CERTIFICATE OF TRANSLATION

Sir:

S. V. RAMAN, a translator, residing at Kolkata/India hereby

states:

(1) that I know well both the German and English languages;

(2) that I translated the attached document identified as corresponding to German Application No. 101 07 600.2, filed in Germany on February 17, 2001, from German to English;

(3) that the attached English translation is a true and correct translation of German Application No 101 07 600.2, to the best of my knowledge and belief; and

(4) that all statements made of my own knowledge are true and that all statements made on information and belief are believed to be true and further, that these statements and the like are punishable by fine or imprisonment, or both, under 18 U.S.c. §1001, and that such false statements may jeopardize the validity of the application or any patent issuing thereon.

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By: SVRaman

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Munich, 11 September 2003
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Method for Operating a Photo-voltaic Solar Module and a Photo-Voltaic Solar Module

The invention pertains to a method for operating a photo-voltaic solar module in relationship to incidence of light, and to a photo-voltaic solar module having the features as described in the introductory part of the patent claim 4.

While operating photo-voltaic plants for solar modules of large dimensions, during the course of the day the position of the sun keeps changing and this causes repeatedly partial shades on the surfaces provided with solar cells, which could be caused by neighbouring structures, antennas, trees etc. Even for a small shade area, such temporary shades could lead to significant influences on the performance of a total system made up of several equal modules. On the one hand, the entry of light into the shaded region gets directly reduced, so that the concerned module generates lesser electrical power. On the other hand, the solar cells of a module are as a rule electrically switched in series. Now if the current in the shaded module (portion) (which is also variably dependent on the incidence of light) drops, then this also simultaneously restricts the current on the not shaded neighbouring cells of the same module. Moreover, the current flow of further modules connected in series gets restricted.

In order to restrict these unavoidable disturbance effects, one subdivides each solar module or each total system into several part systems ("strings"). Each of these has an own converter ("string-converter"). Due to reasons of standardization, these converters have a minimum power of 700 watts. This corresponds to the power generated by a photo-voltaic unit which is approx. 7 to 8 m^2 large.

In such an array, with modern electronic equipment and several modules connected in series, a photo-voltaic voltage of up to approx. 500 – 600 volts is generated and processed, whereby a single solar cell has an operating voltage of 0.5 volts. Consequently, such a string can comprise of approx. 1000 to 1200 single solar cells. A strong local shading of a few solar cells (1 to 5% of the total surface) could then bring about a power loss of 75% of the total system. It is generally known, how to allow the current flow, bypassing shaded or damaged solar cells through so called bypass-diodes, so that their shortage cannot have such an influence on the total system. The bypass-diode allows a short circuit current flow only when the inner resistance of the solar cells exceeds the voltage drop on the diode.

From the document EP-B1-0 896 737, we know of a photo-voltaic solar array with an integrated switch-off device, which neutralises the electrical power of the module when it is activated by an external switching device. This device is however not supposed to restrict the negative consequences of partial shadings, but is supposed to render the concerned solar module non-functional, if for example it has been assembled in an unauthorized manner. Manipulations on this switch-off device are only possible after destroying the total module.

We know of solar elements (DE-A1-42 08 469) whose solar cells serve as sensors for measuring the actual sun radiation. The value determined from these cells can, for example, be used for determining the momentary sun radiation on the concerned module with the help of display indicators.

From the document US-A-4, 175, 249, a self-controlling photo-voltaic solar cell array is known, in which in one array of several identical current-generating solar cells, an additional, independent solar cell is used only as sensor for the light incidence. This sensor-solar cell is subjected to the same temperature and light conditions as the current-generating solar cells. Its no-load voltage is used as measuring signal, amplified and compared with the output voltage of the other cells at that moment. Depending on the results of this comparison, the solar cells of the array can be switched automatically through relays in different series and parallel circuit conditions. In this way, the respective maximum attainable output charge voltage can be got ready.

It is the task of this invention to create a method for operating the solar module in relationship to light incidence and, based on an array according to the already mentioned US-patent, produce an improved solar module under consideration of the effects of partial shading.

This task is fulfilled with the help of the features as mentioned in the patent claim 1 with respect to the method, and with the help of the features as mentioned in the patent claim 4 with respect to the solar module. The features mentioned in the corresponding sub-claims present advantageous extensions of these objects. Claim 14 is directed towards a series connection of several solar modules with at least one solar module equipped as per the invention.

Based on the already known automatic control of the power of the solar module dependent on light incidence, the invention suggests automatic determination of a partial shading through comparison of light incidence on at least two different points of a flat module, and if required, to introduce a bypass which allows a current flow bypassing the shaded module (portion). Although the last mentioned would thus be practically "taken from the supply", the current flow in the further solar cells or modules which are connected in series and not shaded, are no longer handicapped. As a result, the electrical power of the switched-off module is non-existent for the duration of shading or the switching time of the bypass; however, the momentary capacity of the other solar cells or modules continues to be available to the full extent.

The mentioned partial shading can be determined directly by evaluation, e.g. difference formation in the output voltages or output currents of the sensor cells. However, also an indirect determination is possible, in that the shading-induced different temperatures of the sensor cells are determined and evaluated in the evaluation circuit as difference signal. If required, one can even dispense with a separation of sensor cells from the other solar cells and use them also for current generation within the series circuit.

In an extension of the invention, in any case for modules with particularly large surface area expansion, several sensor-solar cells are provided which respectively monitor pair-wise a certain surface region and can always control the desired switching-off of this surface region. The prerequisite for this is however, that in the module itself, corresponding switching devices are foreseen, or that the output lines of each of the separately switchable surface regions is guided outward, in order to be able to bridge them there by mean of a switching device.

Simultaneously with the bridging of the poles of the switched-off module or module portion, one or both lines are completely separated. In this way one can avoid that the voltage supplied by other modules parks itself on the switch-off module or module part and overloads it. This separation can be done simply with the help of a changeover contact.

The switching device can comprise of electro-mechanical or electronic switching agents (relays, controllable semi-conductor switches like transistors, thyristors).

The solar module further comprises of an electronic evaluation circuit. which introduces the switch-off sequence only within a certain tolerance field or above a certain threshold value of the difference of the sensor signals. The last mentioned can be derived from the no-load voltage of the solar cells used as sensor, or (if they are not connected in series). from their current, or even indirectly, as already mentioned, from the momentary local temperature in the region of the sensor cells, if this can be determined with suitable agents.

In this design of the solar module, it is of significant advantage that the sensor-solar cells can have the same design construction as the solar cells used for current generation. Consequently, a solar module can be produced outside the conventional crystalline technology, even over large surfaces in thin-layer technology. This has the advantage that one can later separate the individual solar cells from one another or especially also separate the sensor cells by means of structuring or subdividing the continuous layers according to the state-of-the-art technology. Only while laying the electrical contacts, the sensor cells must be treated in a special manner. Their outer contacts must be laid separated from those of the other (to be connected in series) solar cells.

In another design form, the sensor cells are left in series connection and their actual voltages are determined by parallel voltage tapping. After galvanic de-coupling, e.g. by means of opto-coupler, these voltage signals can serve as input signal of the evaluation circuit. Similarly, an additional temperature provider can also be foreseen.

It is obvious that the switching sequences released by monitoring the partial or local, temporary shading, are foreseen only for temporary switching-off of the solar module: after restoring uniform light incidence on the respective concerned sensor-solar cells, it again becomes automatically active or gets connected to the supply network. Setting in of darkness or similar other shadings on the entire surface of the solar module will not have any effects on the switching device in the hitherto described form.

Further details and advantages of the object of the invention can be obtained from the drawing of two design examples and the subsequent description.

The following are shown:

Fig.1 A simplified block circuit diagram of a first design form of a solar module;

Fig.2 A similar block circuit diagram of another design form.

According to fig. 1, in an already known method, several solar cells 2 are connected to one another in series in a photo-voltaic solar module 1. The solar module 1 further has two outer contacts 3 and 4, on which the output voltage of a solar cell array lies during operation, or from which the electrical power of the solar module 1 is taken away. The already mentioned bypass-diodes, which could be allocated to individual solar cells or groups of solar cells, are not shown here due to simplification.

In most applications, several such solar modules 1 are connected to one another electrically in series, in order to achieve operating voltages of several 100 volts. This means that the entire current from pre-connected solar modules must also flow through the module shown here. If this alone is also partially shaded or if the light incidence only on this module gets reduced, its output power sinks. Its resistance increases and hence blocks the current flow also the other modules.

According to the invention, the solar module 1 further comprises of a first solar cell 5 and a second solar cell 6 which are connected independent of the solar cell 2, and are defined as sensor cells for the momentary light incidence. In the real finish, they are arranged with a large distance from one another, e.g. near the edge of the solar module 1. Their outer terminals, on which respectively a measuring voltage U_5 or U_6 is indicated here as a representative factor, are guided to an evaluation circuit 7 which is shown only symbolically. The latter is foreseen for activating a switching device 8 whose function is explained later. Measuring currents I_5 and I_6 are also shown by the dash-dotted arrows, which similarly can also serve as a measure of the momentary incidence on the sensor cells 5 or 6 in the evaluation circuit 7.

The border frame drawn around the solar module 1 symbolizes that all mentioned components, with the exception of the outer terminals 3 and 4, can be accommodated within one assembly unit.

In the version as shown in fig. 2, in one solar module 1' both the sensor cells 5 and 6 are included in the series connection of the solar cells 2 for otherwise unchanged configuration. By means of (additional) measuring lines, which again are marked pair-wise by the measuring

voltages U_5 and U_6, the momentary output voltage of both cells at both their terminals are tapped in a high-ohmic manner. Of course, the tapping of the measuring voltages should not negatively affect the output of sensor cells 5 and 6 within the series circuit. According to fig. 1, these measuring voltages are fed to the evaluation circuit. As compared to the initially described design form, this configuration has the advantage that the sensor cells remain included in the current production of the solar module 1'. However, the parallel measuring lines have to be additionally introduced and the measuring signals should be galvanic-de-coupled in an appropriate manner.

The switching device 8 has a still condition in both design forms, during which it creates a connection between the series circuit of the solar cells 2 and the outer terminal 4 of the solar module 1 or 1'. In this condition there is a continuous current path from the outer terminal 3 via the series circuit of the solar cells 2 to the outer terminal 4. In the activated (indicated as dashed lines) condition, the switching device creates a short circuit between both the outer terminals 3 and 4 of the solar module 1 / 1'. At the same time, it separates the series circuit of the solar cells 2 from the output terminal 4. Thus it is ensured, that no voltage from outside acts on the series circuit. Although the switching device 8 is shown here as electro-mechanical switch (relay) for the sake of clarity, it is evident that in its place also suitable semi-conductor switches can be used.

The evaluation circuit 7 comprises of, among other things, a comparing circuit as per the state-of-the-art technology, with the help of which any fluctuation between the output signals (e.g. voltages U_5-U_6 or I_5-I_6) of both sensor-solar cells fed to it, is determined. If required, it can also be provided with agents for galvanic de-coupling of the signals of the sensor cells 5 and 6. According to the array shown in fig. 2, obviously an evaluation of the currents by both the sensor cells would not yield the desired results because these are compulsorily always the same on account of the series connection.

If there is uniform light incidence the entire area of the solar module or at least on both the sensor-solar cells, then their output voltages or output currents do not vary or do so only insignificantly. If as a result of local shading of the solar module, less light falls on one of the sensor-solar cells than on the others, then a clear difference occurs between their output voltages (as in the array as per fig. 1 between the currents). This is compared with pre-given (stored in an adjustable manner in the evaluation circuit) threshold values. If the difference

exceeds the threshold value, a switching stage of the evaluation circuit 7 activates the switching device 8 in the activated condition. Through the thus created direct (bypass-) connection between both the outer terminals 3 and 4 of the solar module, current can flow out unhindered from the pre-connected or post-connected additional modules. At the same time, an unproductive current consumption of the switch-off solar module is safely prevented.

If the local shading of the solar module is lifted (e.g. by means of the changing sun position), or other similar light incidence conditions occur on both sensor-solar cells, then the difference of the output voltages, or currents in fig. 1 of both sensor-solar cells gets reduced towards zero. The evaluation circuit 7 determines this and guides the switching device 8 again back to its standstill position, if required with a certain switching delay (hysteresis). The solar module 1 is again switched ready for releasing power.

WE CLAIM

1. Method for operating a photo-voltaic solar module with a number of solar cells electrically connected between two outer terminals in series, in relationship to the momentary light incidence,

in which

– there is determination of at least two variable measuring signals independent of light incidence, on at least two solar cells arranged within the solar module at a distance from one another and defined as sensor cells;

– there is evaluation of these measuring signals in an evaluation circuit;

– there is bridging of the outer terminal of the solar module in case there is a variation of the measuring signals above a pre-give threshold value, with the help of a switching device which can be controlled by an evaluation circuit; and

– there is removing of the bridge of the outer terminals if a variation of the measuring signals occurs, which is below the threshold value.

2. Method as per claim 1,

in which

electrical output signals (voltage, current) generated directly by the sensor cells are evaluated as measuring signals.

3. Method as per claim 1 or 2,

in which

temperatures determined on the sensor cells are used as measuring signals.

4. Solar module (1) with a number of individual solar cells (2) individually connected to one another electrically in series, with at least one solar cell (5, 6) subjected to the same condition, as sensor for the momentary light incidence of the solar module, and with a switching device (8) which can be directly controlled by the sensor, for influencing the electrical power of the solar module,

in which

at least two solar cells (5, 6) of the solar module (1) arranged with great distance from one another, are foreseen as sensor, from which the generated measuring signals in relationship to the momentary light incidence are fed to an evaluation circuit (7) and

are here compared to one another, and the evaluation circuit (7) with the help of the switching device (8), in case of the fluctuation between both measuring signals crossing a threshold value, switches on a bypass which bridges the series circuit of at least one part of the solar cells (2) of the solar module (1).

5. Solar module as per claim 4,
in which
the solar cells (5, 6) defined as sensors are not included in the series connection of the other solar cells (2), and for transmission of the measuring signals are connected only to the evaluation circuit.

6. Solar module as per claim 4,
in which
the solar cells (5, 6) defined as sensors are included in the series connection of the remaining solar cells (2) and for transmitting the measuring signals, are additionally connected to the evaluation circuit.

7. Solar module as per one of the claims 4 to 6,
in which
the evaluation circuit (7) and the switching device (8) are arranged in the solar module (1) itself.

8. Solar module as per one of the claims 4 to 7,
in which
a large number of sensor-solar cells are provided, which are respectively allocated pair-wise to a definite surface region, and for each of these surface regions there is a switching device.

9. Solar module as per one of the above mentioned claims 4 to 8,
in which
the switching device (8) is further foreseen for separating the series connection of the solar cells from at least one of the outer terminals (3, 4) on activation through the evaluation circuit (7).

10. Solar module as per one of the above mentioned claims 4 to 9,
in which
the solar cells (5, 6) used as sensors are arranged close to the edge of the flat solar module (1).

11. Solar module as per one of the above mentioned claims 4 to 10,
in which
the switching device (8) comprises of an electro-mechanical relay.

12. Solar module as per one of the above mentioned claims 4 to 10,
in which
the switching device comprises of a controllable power-semiconductor switch.

13. Solar module as per one of the previous claims,
in which
the evaluation circuit (7) switches over the switching device (8) again to standstill condition on attaining a uniform light incidence on both sensor-solar cells (5, 6).

14. Series connection of several solar modules with at least one solar module as per one of the previous claims 4 to 13.

Abstract

In a solar module (1) with a number of individual solar cells (2) connected electrically in series to one another, with at least one solar cells (5, 6) subjected to the same condition and not connected to the remaining solar cells, as sensor for the momentary light incidence on the solar module and with a switching device (8) directly controllable by the sensor for influencing the electrical output power of the solar module, **according to the invention** at least two solar cells (5, 6) arranged at a large distance from one another are foreseen as sensors, whose output voltages or output current are fed to an evaluation circuit (7) and compared there with one another, and the evaluation circuit (7) activates with the help of the switching device (8) a bypass bridging the series connection of the solar cells (2) of the solar module (1) in case of a difference between both the sensor output exceeding a threshold value.

[Fig. 1]